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## INTRODUCTION

For more than a decade, individual research groups at Goddard Space Flight Center and the University of Maryland have participated in experiments and observations which have led to the emergence of new disciplines. Having recognized at an early stage the critical importance of maintaining detector capabilities which utilize "state of the art" techniques, the two institutions formulated a joint program directed towards this end. This program has involved coordination of a broad range of efforts and activities including joint experiments, collaboration in theoretical studies, instrument design, calibrations, and data analysis. As part of the effort to provide a stimulating research environment, a series of joint seminars on topics in Astrophysics and Space Physics has been instituted and is held regularly at the University. Many phases of the cooperative effort directly involve faculty, research associates and graduate students in the interpretation of data which is carried out at the Goddard Space Flight Center as well as on campus. Two aspects of this joint program are particularly important. The first is the close tie between scientists at Goddard and the faculty and graduate students at Maryland. This has resulted, for example, in Ph.D. thesis research for a number of graduate students and has been a vital part of the program. The second aspect has to do with the development of advanced instrumentation for space experiments and the cooperative analysis of data from such experiments.

Detailed information on the research projects is available in the annual proposals submitted for this grant. The following are summaries of studies undertaken and progress made under this contract. A representative bibliography is also included.

## UNIVERSITY OF MARYLAND

The Space Physics Group has been involved in the interpretation of observations from two low energy ion and electron experiments currently in earth orbit. These experiments, designed and fabricated by the group at Maryland, are part of the instrument payloads of the IMP 7 satellite (Explorer 47) launched in the fall of 1972 and the IMP 8 satellite (Explorer 50) launched in the fall of 1973. These projects are under the direction of Professor Gloeckler, the Principal Investigator, and Dr. Ipavich, the Project Director. Our IMP-7 and -8 experiments constitute a unique data base of 22 spacecraft-years and is still being actively analyzed.

The group has undertaken several years of participation, under Dr. Gloeckler's direction, in data analysis and interpretation from the Low Energy Charged Particle experiments on Voyagers 1 and 2 to Jupiter, Saturn and Uranus, and beyond.

There has been considerable analysis of data from the Low Energy Nuclear and Ionic Charge Detector experiments on the ISEE-1 and ISEE-3 (ICE) spacecraft launched in October 1977 and August 1978, respectively. Professor Gloeckler and Dr. Ipavich are among the co-investigators on these experiments which involve international cooperation with Dr. Dieter Hovestadt of the Max-Planck-Institut in Garching, West Germany. These long flying, well operating experiments continue to produce good data and many publications have resulted, including the Ph.D. dissertation of Dr. A.B. Galvin, now a co-investigator also.

Professor Gloeckler, Principal Investigator, and Dr. Ipavich, co-investigator, have had considerable success with an instrument developed to measure magnetospheric ions on the Charge Composition Explorer (CCE) in the Active Magnetospheric Particle and Tracer Explorer (AMPTE) mission. In

collaboration with the Max-Planck-Institut/Lindau and the University of Braunschweig, both in Germany, they created the CHarge Energy Mass (CHEM) spectrometer that is the only instrument on the CCE spacecraft to continue to function normally all the time, since launch in August 1984. CHEM is the first instrument ever flown to combine the detection techniques of electrostatic deflection, time-of-flight measurements, and total energy measurements.

Professor Gloeckler, principal investigator, and Dr. Ipavich, co-investigator have been involved in the development of an instrument to measure the solar wind ion composition on the ESA spacecraft on the ULYSSES (Solar Polar) mission, an international collaboration involving research groups in Switzerland, Germany and Denmark, as well as Goddard and the University of New Hampshire. The ULYSSES spacecraft was supposed to have been launched in 1986, but, of course that has been postponed.

Professor Mason was the Project Director at Maryland, and Professors Mason and Gloeckler were co-investigators in an international collaboration with Caltech (PI institution), Goddard, the Max-Planck-Institut in Germany, and the University of New Hampshire, in the development of an instrument to measure transthermal ions on the NASA spacecraft in the Solar Polar Mission.

The development of a new and improved low energy, large geometry factor, particle detector system based on combining total energy measurement techniques with a time of flight determination from secondary electron emission measurement, is under the direction of Professors Mason and Gloeckler.

We reported the first measurements of very energetic ( $>100$  keV)  $O^+$  ions in the earth's plasma sheet using data from the UMD/MPE ULECA sensor on ISEE-1. Our initial analyses concentrated on data from March 4-5, 1981 (when the

spacecraft was located at geocentric distances  $\sim 15-20 R_E$  in the magnetotail) and on data from the 22 March 1979 substorms investigated by the Coordinated Data Analysis Workshop (CDAW) -6. (This latter data set allowed us to compare the behavior of energetic ( $>100$  keV)  $O^+$  ions with that reported for .1 to 16 keV  $O^+$  ions by the Lockheed plasma composition experiment on ISEE-1 during the same time period.) We have since been investigating energetic  $O^+$  in magnetospheric boundary layers.

The MPE/UMD experiments on ISEE-1 and ISEE-3 are currently being used by the University of Maryland Space Physics Group in conjunction with the Max-Planck-Institut in Germany in the study of the upstream particle populations known as the diffuse and the reflected components. Utilizing both rate and pulse height data (primarily in the energy range of  $\sim 10$  to 130 keV per charge), we are investigating the compositions, rate profiles, spectral characteristics, and charge state distributions of these upstream particle enhancements. Our observations are not only providing important constraints on proposed acceleration models for upstream phenomena, but are also stimulating theorists to re-examine existing models describing shock acceleration in the solar system and in the interstellar medium.

Using data from the UMD/MPE ULECA sensor on ISEE-1, we are continuing work on a statistical survey correlating diffuse ion event intensity and anisotropy variations for 30 keV and 130 keV protons with solar wind and bow shock parameters. In particular, we are doing a multiple regression analysis in order to isolate the dependence of particle intensity on distance from the bow shock, solar wind density, solar wind speed, geomagnetic activity ( $K_p$ ,  $Dst$ , AE indices), free-stream Mach number, and time of connection of the interplanetary magnetic field with the bow shock before convection past the spacecraft. We are also attempting to distinguish between the intensity

dependence on the angle between the magnetic field and the radial (sun-earth) direction versus the angle between the magnetic field and the bow shock normal.

Using simultaneous data from our experiments on IMP 7/8 (at  $35 R_E$ ) and on ISEE-1 (at  $\lesssim 22 R_E$ ), we are studying the spatial dependence of the intensity of upstream events in order to determine both the possible transport of diffuse upstream ions into the magnetosphere and the possible leakage of plasma sheet magnetospheric particles into the upstream region.

The MPE/UMD experiments on ISEE-1 and ISEE-3 and the UMD/MPAe experiment on CCE are being used in an extensive investigation into the charged particle populations of the earth's radiation belts and geomagnetic tail region. The October 1982 to December 1983 excursion of the ISEE-3 spacecraft into the far geomagnetic tail has provided a unique opportunity for correlated studies between the two nearly identical MPE/UMD experiments on the ISEE-1 and 3 spacecraft.

We have recently completed a study of the low energy abundances of heavy ion species in  $^3\text{He}$ -rich flares, using data from the ISEE-3 ULEWAT sensor, and the ISEE-3 VLET sensors. Our results show that the average abundances of the heavy ion species C, O, Ne, Mg, Si, Fe are systematically enriched compared to the composition in large solar flare events. The most striking discovery of this study is that the variations of the heavy ion abundances around the average signature are almost always less than a factor of two.

With the passage of ISEE-3 (renamed the International Cometary Explorer) through the tail of Comet Giacobini-Zinner on September 11, 1985, the ULECA sensor on ISEE-3/ICE has obtained conclusive evidence for the existence of energetic (35-150 keV), heavy ( $\gtrsim 12$  amu), singly charged cometary ions within a distance of  $\sim 1.5 \times 10^6$  km from Comet Giacobini-Zinner.

Using data from the AMPTE/CCE sensor we have identified all atomic charge states of Oxygen from  $O^{+1}$  (which originates in the earth's ionosphere) to  $O^{+8}$  (which originates in the solar corona). We have also discovered large quantities of  $N^{+}$  ions at very high energies (above 100 keV); the behavior of these ions will provide information not only on acceleration processes in the ionosphere but also on the chemistry of the earth's upper atmosphere. The CHEM experiment has also supported the search for artificially injected tracer ions. Lithium and Barium ions were released by one of the other AMPTE spacecraft into the region upstream of the earth's bow shock during the fall of 1984 and in the earth's tail region in the spring of 1985. Observations of these ions by the CHEM instrument have resulted in upper limits for the presence of these ions which place constraints on theoretical models of the acceleration and propagation of ions in the near-earth environment.

With the CHEM instrument spacecraft we have also made the first comprehensive observations of the abundances of thermal and suprathermal  $H^{+}$ ,  $He^{+2}$ ,  $O^{+}$ ,  $O^{+2}$ ,  $He^{+}$ , and  $(C+N+O)^{+3}$  ions in the very quiet ( $Kp = 1^{-}$ ) near earth plasma sheet. For the time period studied we find that the thermal ( $\leq 5$  keV/e) portions of the distribution functions of these ions may be fit to a Maxwellian with a temperature of 2.3 keV for protons and 1.9 keV/e for  $He^{+2}$ . Above 5 keV/nucleon the suprathermal tails of the distribution functions of  $H^{+}$  and  $He^{+2}$  have the form  $f = f_0 [1 + e/(nE_0)]^{-n}$  with  $n = 7.5$  and  $E_0 = 2.3$  and 1.9 keV/e for  $H^{+}$  and  $He^{+2}$ , respectively. Our findings indicate that the plasma sheet composition is similar to that of the quiet time ring current, and the solar wind is the dominant plasma source of these regions during non-disturbed times.

A survey of the ring current ionic composition during geomagnetically active periods in late 1984 and early 1985 using data from the CHEM

spectrometer has enabled the determination of the characteristics of the ion population in the energy range 5-315 keV/e at the L-value of maximum energy density ( $L_{\max}$ ) on several different active days.

We currently have some limited solar wind data available from the UMD/MPE Ultra Low Energy Charge Analyzer (ULECA) sensor on ISEE-3 and the UMD/MPAe CHEM experiment on CCE.

The low energy section of the ULECA sensor on ISEE-3 is designed to measure solar wind flows with bulk speeds  $>550 \text{ km sec}^{-1}$ . Using this sensor we have recently reported the first measurements of Fe charge states in two coronal hole-associated high speed streams. Our sensor's simultaneous determination of energy per charge and total energy (measured by solid state detectors) produces an immunity to the instrumental problems caused by the very high kinetic temperatures in these high speed solar wind flows. Our measurements show that the solar wind emitted from coronal hole regions is characterized by lower charge states (hence lower coronal temperatures) than is the solar wind emitted from the quiet corona.

Another well-known source of high-speed solar wind is flare-related plasma. We have been able to determine the charge states of Fe in a solar wind flow which originated near a solar flare site and have found that this flow is characterized by much higher than normal charge states, implying that the solar flare effectively heated the solar atmosphere out to distances of several solar radii.

By combining our Fe observations with solar wind proton measurements by the Los Alamos National Laboratory (LANL) experiment on the same spacecraft we have determined that the coronal hole flow have an iron-hydrogen velocity difference slightly higher than the Alfvén speed, consistent with the existence of an extended wave energy input in coronal hole streams.



Although our CCE plasma composition experiment (CHEM) was primarily designed to measure magnetospheric ions (CCE's apogee is  $8.8 R_E$ ), occasional magnetosheath excursions have allowed us to sample solar wind composition as well. We have been able to resolve - for the first time - solar wind Carbon from other ions with the same mass per charge ratio. Our preliminary analysis of the CHEM data from the CCE magnetosheath transversals indicates that the solar wind C/O ratio is surprisingly variable (within the range  $\sim 0.3$  to  $0.7$ ) and that the equilibrium coronal temperature for Carbon is consistently below that of Oxygen. We have also found some abrupt changes in the charge state composition of these elements. We are currently refining our analysis of these events and will expand our data set as additional magnetosheath crossings occur.

#### GODDARD SPACE FLIGHT CENTER

Several research programs have been conducted by the High Energy Astrophysics group at Goddard under the overall direction of Dr. F.M. McDonald, until 1983, and now Drs. Boldt, Fichtel and Ramaty.

Under the direction of firstly, Dr. McGuire, and then Dr. von Rosenvinge, considerable work has been done on the analysis and interpretation of solar, galactic, interplanetary, Jovian and Saturnian particle data from the Goddard experiments in the IMP series, the Helios series, Pioneer 10 and 11, Voyager 1 and 2, and the ISEE-3/ICE spacecraft. Dr. Ormes has undertaken the interpretation of the isotopic composition of galactic cosmic rays from Goddard balloon experiments.

We continue to analyze data from the Pioneer 11 encounter with Saturn and the two Voyager encounters with Jupiter and Saturn. The Goddard instruments continue to yield important information in the areas of elemental composition,

flow patterns, and the spatial structure of energetic particle fluxes in both the Jovian and Saturnian magnetospheres.

Using the combined IMP-8 and ISEE-3 data bases over the period 1978-1983, we have identified some 80 solar particle events with measurable fluxes of electrons above 3 MeV for which there are soft X-ray observations. Based on their signature in soft X-rays, we have classified these events as being either impulsive (<1 hour) or long duration (>1 hour) events. We find that the events originating with impulsive flares are associated with intense meter wavelength Type III bursts, indicating the presence of high fluxes of electrons on open field lines.

We have made substantial progress in understanding the nature of  $^3\text{He}$  events. Comparison with low energy electron data now strongly suggests a good correlation with so-called scatter-free electron events, implying both that  $^3\text{He}$  events are solar in origin (also shown by the highly anisotropic  $^3\text{He}$  fluxes we observe) and come dominantly only from regions well-connected to the observing spacecraft. We are currently exploring the correlation of these events with, for example, solar radio and X-ray data, specifically in the context of the relativistic electron study, to examine the hypothesis that  $^3\text{He}$  events may be associated with impulsive flare acceleration.

Work is also in progress on gamma-ray burst data from the ISEE-3 and Solar Maximum spacecraft. The emphasis is on the determination of gamma-ray burst source locations using the method of multi-spacecraft timing of the arrival of the burst wave front. There is considerable interest in this work since optical flashes in the direction of several known gamma-ray burst sources have recently been observed. The group is also involved in continuing ground-based studies of the optical emission associated with gamma-ray bursts.

Dr. Teegarden's group has been involved in the analysis of data from the

successful flights of the Low Energy Gamma-Ray Spectrometer (LEGS). This instrument on the Palestine, Texas balloon flight of May 1969 has more sensibility and higher resolution than instruments flown previously. The second successful flight of the LEGS experiment took place in September 1980. The primary targets HER X-1 and the crab nebula, were each observed for approximately 7 hours. The instrument performance was exceptional during these observations and a large amount of high quality data was obtained. There was a successful flight of the LEGS experiment from Alice Springs, Australia in November 1981. Observations were performed of the active galaxy Centarus A and the gamma-ray source at the center of our own galaxy. The variability of the positron annihilation line at 511 keV from the galactic center was confirmed by our observation of this source in a low state of emission. The LEGS experiment was flown again from Australia in December 1984. The source VELA X-1, a pulsating binary, was observed successfully. Data analysis continues.

A new second-generation balloon-borne gamma-ray spectrometer called the Gamma-Ray Imaging Spectrometer (GRIS) has also been developed. This experiment consists of an array of seven high-resolution Germanium detectors surrounded by a thick massive NaI shield. There is also an active NaI coded-aperture mask to produce gamma-ray images over a 9 by 15 degree field-of-view. A late 1986 first flight has been planned.

Drs. Boldt, Holt and Serlemitsos have directed the analysis and interpretation of X-ray data, concentrating on X-ray binary systems, the diffuse X-ray background, Seyfert I galaxies, X-ray emission from superclusters, and extragalactic sources. Some of the work undertaken is indicated in the following paragraphs.

Several Ph.D. dissertations have been completed in the area of X-ray

astronomy over the past several years.

One student found an excess variance above that expected for an Euclidean distribution of constant sources, implying an evolution of sources, a new population of sources, or a large scale clumping of either sources or diffuse emission. His tentative measurement of a large scale anisotropy in the diffuse x-ray background is consistent with the velocity and direction of the dipole anisotropy in the microwave background.

Another student used careful statistical analysis techniques to perform a very sensitive search of Goddard HEAO-1 data for rapid x-ray variability in active galaxies. He concluded that the non-variability of the majority of the 38 active galaxies he studied indicates that their x-ray producing plasma is either stable or fills a large volume relative to the central object powering the galaxy. He also argued that the source NGC6814, which shows factor-of-two changes in intensity in periods as short as two minutes, is dominated by variable emission from an injection mechanism operating near the central object.

Circinus X-1, a highly variable eccentric X-ray binary system whose compact member is a black hole candidate, was modeled by another student to study the accretion process in compact binary x-ray sources. Using observations from Goddard instruments on four x-ray satellites to model Cirinus she has been investigating the extent which her thesis results apply to stellar black hole candidates as a class.

In his thesis, "X-Ray Spectra of Supernova Remnants", another person showed that the X-ray spectra of three supernova remnants, Puppis A, Tycho, and Kepler, as observed by the Einstein Observatory Solid State Spectrometer, can be understood in terms of time-dependent ionization of shock-heated gas.

Another graduate student searched all the source-free regions of the HEAO

1-A2 all-sky data base for evidence of rapidly flaring X-ray transients. Six such transients were found, some of which could be ascribed to hot "superflares" from dMe stars, but none of which were related to gamma ray bursts. In the remainder of her thesis research, this student has extended her search for fast transients to the galactic plane region, as well as other interesting areas of the sky, such as the Large Magellanic Cloud, which were not included in the original search because of the presence of strong X-ray sources.

Yet another student has used the X-ray spectra from the HEAO 1-A2 experiment and X-ray images from the Einstein Imaging Proportional Counter to fit density and temperature profiles, assuming a polytropic equation of state for the hot gas in clusters. By using the inferred density and temperature profiles and assuming that the gas is in hydrostatic equilibrium, he then derived the form of the cluster potential and thus measured the mass of the "dark matter". His findings suggest that previous work has severely overestimated the dark matter needed to bind clusters.

Our analysis of the cosmic ray data accumulating from our multiple spacecraft experiments continues to yield new results in modulation and galactic cosmic ray studies, in our understanding of the acceleration of solar energetic particles, and in our knowledge of the physics of planetary magnetospheres.

In interplanetary studies, our focus is on long-lived, radially propagating shock waves in the outer heliosphere and on the fine structure and large scale geometry of shocks at 1 AU.

In solar energetic particle (SEP) studies, we continue an analysis of spectral shapes, both on average and in comparison to  $\gamma$ -ray events, a comparison of observed with calculated ion fluences in  $\gamma$ -ray events, and a

study of correlations between SEP events and coronal mass ejections. We are also progressing in flare composition and SEP propagation studies using data from multiple spacecraft.

In planetary studies, a mass of new information has been obtained in the Voyager encounters with Jupiter and the Pioneer 11 and Voyager encounters with Saturn. Analysis is underway on the new data obtained during the Voyager 2 encounter with Uranus in January 196.

Cosmic ray intensity observations, from Pioneer 10 and other spacecraft, associated with enhanced solar activity during the onset of cycle 21, and observations over an extended range of energy and heliocentric distance, have led to the understanding that changes in the 100-200 MeV/nucleon flux had time delays corresponding to an outward propagation velocity of some 550 km/sec. This suggests that recently discovered, moderately long-lived, radially propagating shock waves in the heliosphere may play a key role in long-term modulation.

The "anomalous component" of the energetic particle population has been observed to involve enhanced quiet-time fluxes of He, N, O, and Ne and its properties cannot be understood in terms of conventional modulation theory.

Cosmic ray, field and plasma data have been analyzed from the Voyager, Pioneer, IMP 8, Helios and ISEE spacecraft to map out more details on long-lived shocks and their effect on galactic cosmic rays. Of particular interest has been how the relatively large amplitude but simple and temporally short structures observed in the outer heliosphere might evolve from the more complex and chaotic multitude of radial shocks seen in the inner heliosphere at solar maximum, what the large scale geometry of the outer-heliospheric shocks is, and how this geometry might interact with large-scale heliospheric magnetic field geometry to produce modulation effects. Part of this effort

has also involved numerical modeling of the anomalous component to try to obtain a consistent picture of the observed gradient and spectral features.

Having resolved isotopes from H through O for the Pioneers and H through Ne for the Voyager experiments the resulting measurements give a measure of the grammage through which low-energy interstellar ion populations propagate into the heliosphere.

Observations of medium energy gamma ray sources have been undertaken, concentrating on the galactic center emission and point sources in the Cygnus and anticenter regions. Drs. Fichtel and Thompson have been directing these studies.

A large gas Cerenkov detector, recently flown by balloon to the top of the atmosphere to study the energy dependent variation in the cosmic ray charge composition, has provided information on the lifetime of galactic cosmic rays at the highest energies for which direct measurements have been made. Data analysis in this area is continuing.

Under the direction of Dr. Ramaty theoretical research in extragalactic astronomy, high energy cosmology, compact object astrophysics, and solar physics has been conducted. Such theoretical studies are essential in order to determine the most important directions to pursue in future measurements, the interpretation of existing observations within a self consistent framework, and in the development of new experimental techniques. Theoretical research is pursued in x-, gamma- and cosmic ray astrophysics, as well as in extragalactic astronomy, cosmology compact object astrophysics, and solar physics.

A program in cosmic ray astrophysics with particular emphasis on acceleration and modulation problems has been pursued. Particular emphasis is given to the physics and radiation mechanisms in compact sources both on

stellar and galactic scales, such as pulsars and active galactic nuclei. A significant fraction of this research is the study of gamma ray spectroscopy associated with  $e^+e^-$  annihilation lines, both in active galactic nuclei (including the galactic center) and in  $\lambda$ -ray bursts. Research in high energy radiation from pulsars, with particular emphasis on processes in superstrong magnetic fields, is being conducted, while another researcher is modeling the emission of similar radiation from active galactic nuclei. The examination in detail of the physics of broad emission line checks of the latter objects is also being carried out.

Research pertaining to the interplay between high energy physics and cosmology is being performed in collaboration with the Bartol Research Foundation.



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